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Sensory and affective response to chocolate differing in cocoa content: a TDS and facial electromyography approach

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Highlights

- A novel study to measure facial changes using facial electromyography (EMG) during the consumption of a complex food system (chocolate).
- Significant variation in participants' *corrugator* activity identified during the time period of oral processing when the most dominant taste attributes were most divergent.
- Facial EMG activity is associated with hedonic evaluation of a solid complex food product.
- Evidence to suggest that during consumption facial EMG, specifically over the *corrugator,* can differentiate similar products from the same food category.

Sensory and affective response to chocolate differing in cocoa content: a TDS and facial electromyography approach

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Key Words

Plain chocolate, facial electromyography, temporal dominance of sensation (TDS), oral processing, valence.

Abstract

Existing research has offered insight into facial activities and their associations with hedonic liking during the consumption of basic food samples and suggests facial changes during consumption are linked to the hedonic evaluation of tastes and, thus related to the taster's perception rather than the tastes themselves. This study tests whether, during the consumption of commercially available dark chocolate, a complex food product, which can be high in bitterness but expectedly so, how facial activities are linked to the bitterness levels and the hedonic liking of the samples. To do this we carried out two studies with untrained consumers, the first of which captured temporally dynamic sensory perception during the consumption of dark chocolate samples of 36% and 85% Cocoa content, using the Temporal Dominance of Sensations (TDS) approach. The second study captured facial EMG over the *corrugator* and *zygomaticus* muscles during the consumption of dark chocolate samples (36%, 70%, and 85% Cocoa). Specifically, the aim of this research was to investigate whether *corrugator* activity had a greater association with bitterness perception, linked to Cocoa, or hedonic evaluation. Capturing the dynamic sensory profile of chocolate samples allowed an investigation into the time points most evident of sensory variation related to the bitterness and sweetness of the taste, allowing insight into whether facial activities also deviated during this time. These data offer evidence to suggest that *corrugator* was associated with hedonic evaluation during consumption of the samples, with the most liked samples (being those with 70% and 36% Cocoa) eliciting similar *corrugator* activities and less activity than the least liked 85% cocoa content sample; however, there was also evidence to suggest a significant variation in participants' *corrugator* activity during the period of oral processing when bitterness was most evident in the 85% cocoa sample and sweetness was most evident in the 36% cocoa sample (i.e., the time when bitterness and sweetness were most divergent) Further investigation showed a variation in facial activities elicited during consumption of the 36% Cocoa sample based on whether individuals were part of the group who favoured the 85% Cocoa sample or the group favouring the 36% Cocoa sample. The findings, therefore, suggest facial EMG, specifically over the *corrugator*, appears to be related to the hedonic evaluation of a complex food product and not the taste itself. Furthermore, being aware of the time points where sensory variations are most apparent between samples can allow for targeted investigation into facial EMG and its ability to distinguish food samples.

1. Introduction

As the food industry strives to develop tools that allow for greater insight into consumer affective response to foods there has been a move towards the use of methods that allow for the capture of temporally dynamic, implicit responses to foods over and above self-reported conscious measures.

The goal being to achieve a more holistic understanding of the consumer experience, which influences acceptability and buying behaviour. Previous research in the non-food domain has evidenced a negative association between the activity of the *corrugator* muscle (involved in drawing the eyebrows together and down in a frown) and subjective hedonic evaluation of emotional stimuli (Larsen, Norris, Cacioppo, 2003) using facial EMG. Further research has extended this to the food domain, with evidence supporting a negative association between *corrugator* activity and liking ratings of food images, basic tastes, and solid foods (Cannon, Li, Grigor, 2017; Nath, Cannon, Philipp, 2019; Nath, Cannon, Philipp, 2020; Sato et al., 2020; Sato, Yoshikawa, Fushiki, 2021; Wagner et al., 2021). However, to date, published studies adopting paradigms with solid foods have tended to utilise gel-type stimuli (e.g., Sato et al., 2020) and, as such, more work is required to investigate the association between *corrugator* activity and the sensory profile of a complex solid food product, such as commercially available dark chocolate samples. Previous studies have shown a characteristic negative facial expression specifically related to the eyes and forehead that accompanies the tasting of bitterness (Wendin, Allesen-Holm, Bredie, 2011); however, this study aimed to investigate the link between facial activity and subjective hedonic evaluation of dark chocolate, a food known for being bitter in sensory profile, yet liked by many. However, under the banner of the product category “dark chocolate”, sits many different chocolate products varying in their dynamic sensory profiles (e.g., Jager et al., 2014). The aim was to investigate samples varying primarily in Cocoa content, which can also impact taste, flavour and oral-somatosensory aspects of the chocolate, including bitterness perception, to investigate associations between dominant taste attributes, self-reported liking, and facial activities elicited during their consumption.

Research has offered insight into cross-modal associations of perception of chocolate samples based on where they lie on the sweet/bitter continuum (Ngo, Misra, Spence, 2011). For instance, chocolate varying in cocoa content was looked at together with meaningless speech sounds with the findings suggesting that higher cocoa content was associated with sharp word sounds relative to round word sounds, which were associated with lower cocoa concentrations (Ngo, Misra, Spence, 2011). Furthermore, the research suggests perceived bitterness of dark chocolate samples, the main sensory driver of the chocolate, was dependent on cocoa concentration (Lindt 30%, 70%, and 90%). This is interesting, as there are numerous variations which may be present between samples including texture and mouthfeel that can drive consumer response. In line with this idea, a further similar study found evidence that texture and taste can influence associations with speech sounds (Ngo & Spence, 2011). These cited studies give examples of associations of measures captured at one point in time. Thus, when investigating affective responses that evolve during consumption it can be arguably more of a challenge to understand the sensations driving these changes at any given time. However, by capturing the dominant attributes demanding the consumers' attention during the consumption of chocolate there is scope for gaining a better understanding of the sensations that may be driving the consumers' dynamic affective response.

Dynamic sensory profiling of products can be carried out using methods such as the Temporal Dominance of Sensations (TDS) method, which allows for dynamic capture of the sensation most taking the consumer's attention during the oral processing of food (Pineau et al., 2009). This information can be used to construct a sensory profile of the sample. The method is often carried out using a highly trained panel; however, research has shown it can be used with a novice panel (e.g., Albert et al., 2012; Hutchings et al., 2017), and as the sensory profile captured by a highly trained consumer panel is likely to differ from an untrained panel (see Ares & Varela, 2017 for a discussion) it could be argued transferring findings between the groups may be misleading. Thus, to better understand any associations between the sensory profile of a food and the facial responses it evokes when being consumed, it is thought important that sensory profiles are captured by a consumer group with the same level of sensory training. However, an important factor, when testing untrained samples is their ability to articulate the sensory properties of food, thus, attributes should be chosen carefully. For instance, a study investigating the sensory descriptors given to dark chocolate by consumers found they are limited in their abilities to describe dark chocolate, with taste, such as bitterness and sweetness, and mouthfeel attributes, such as melting, being key (Thamke, Dürrschmid, Rohm, 2009). Importantly, these attributes were also shown to have a correlation with the cocoa content of the chocolate samples used; for example, variations were found between a 60% cocoa sample and a 75% cocoa sample (samples from different manufacturers) in terms of how they were perceived on the sweet/bitter continuum with the former being regarded as sweet and the latter as bitter, in line with sugar content which decreases with increasing cocoa (Thamke, Dürrschmid, Rohm, 2009). Thus, one may expect that key attributes linked to taste, such as bitterness and sweetness, are likely to dominate cognitive sensory evaluations and have an impact on evaluations of the pleasantness (valence) of the dark chocolate during the consumption.

Facial EMG allows for muscular activities associated with valence to be captured (Cacioppo et al., 2008). As data are obtained across time, fast automatic responses can be gathered. This may be more beneficial than using interruptive, subjective, self-reporting methods that often only capture static conscious responses. Therefore, by measuring changes in facial activities across the consumption experience it can be possible to gather insights into how affective response changes during dark chocolate consumption. Many previous studies have sought to utilise facial expression analysis technology, which classifies facial movements based on patterns of facial reactions; for example, movement of the eyes and mouth may be classified as a “happy” response. However, evidence has highlighted the fragile association between the basic emotions and their corresponding stereotypical facial expressions (e.g., Barrett et al., 2019; Jack et al., 2012; Ruiz-Belda, Fernández-Dols, Carrera, & Barchard, 2003). This evidence suggests that displayed facial expressions may change based on situational or contextual factors. An additional issue with emotion categorisation software comes from the focus on discernible facial movements; thus, requiring visible activities in areas of the face for measurement. Facial EMG has the benefit of capturing activity that a human eye or automatic facial expression analysis software may be unable to detect (Hess, 2009). Thus, having the potential to capture subtle affective responses to food.

Basic tastes have been shown to be linked to characteristic facial expressions (e.g., Rosenstein and Oster, 1997, Steiner, 1979), with bitterness regarded as an aversive taste evoking facial expressions indicative of an hedonically negative experience (Wendin, K., Allesen-Holm, B. H., & Bredie, W. L., 2011). Research has also shown that some facial reactions elicited during the tasting of bitterness, including frowning increases as perceived bitterness intensity increases, suggesting a dose dependency; however, disentangling whether this is driven by bitterness itself or hedonic evaluation of the tastant is difficult to discern, as increasing bitterness intensity is often linked with decreased perceived pleasantness (Wendin, K., Allesen-Holm, B. H., & Bredie, W. L., 2011). This is not always the case for food products with high levels of bitterness, such as dark chocolate where some consumers may favour a higher cocoa content (often linked to high bitterness levels).

It must be borne in mind that the assessment of food products for basic tastes such as bitterness and sweetness is tied to the hedonic components of foods, as sensory attributes of a food product influence consumer liking of the product. Furthermore, overall liking of a product can also influence ratings of sensory attributes. For instance, research investigating bitterness ratings found these to be conflated with the hedonic properties of jellybeans (Davis & Running, 2023). Thus, the bitterness intensity ratings given by participants in this study may also reflect their liking of the product. Likewise, it is also difficult to tell whether bitterness itself drives facial activity or whether facial responses are solely driven by the hedonic evaluation of dominant attributes, including taste attributes, such as bitterness, during consumption. For instance, it may be that the high level of bitterness in certain high cocoa content dark chocolate can elicit facial activity on its own, thus rendering EMG a poor option for offering insight into hedonic liking of such products. By investigating chocolate samples varying primarily in cocoa content for which TDS graphs have been constructed by an untrained consumer group and capturing self-reported hedonic liking of each sample it may be possible to establish whether responses to bitterness itself and hedonic evaluation can be disentangled during the consumption of commercially available dark chocolate.

However, as drawing attention to sensory aspects of the chocolate during consumption is likely to affect facial displays this study was carried out as two separate experiments using a different untrained consumer group.

1.1. Study aim

The current study consisted of two experiments conducted on demographically similar untrained consumer samples to enable the construction of dynamic sensory profiles of dark chocolate samples varying primarily in cocoa content (Experiment 1) and to capture facial responses linked with during oral processing of dark chocolate samples varying primarily in cocoa content (Experiment 2). Data were analysed to understand the sensory profiles of a 36% cocoa sample and an 85% cocoa sample which allowed for insights into the periods where sensory profiles diverged the most for taste attributes, namely bitterness and sweetness. This experiment included collecting dynamic sensory profile ratings, static bitterness ratings and static hedonic evaluation ratings. It is understood that best practice in traditional consumer sensory settings would be to collect this information at different sessions; however, consumers experience the sensory aspects of foods and evaluate the food for liking at the same time during normal consumption (Davis and Running, 2023). Thus, if one aspect, such as sensory perception, influences ratings on another aspect, such as liking, then information is important and allows for insight into the consumer experience of sensory aspects that drive hedonic evaluations. Arguably, such information would not be gained by combining the hedonic measures of an untrained panel with the sensory measures from a highly trained panel. Furthermore, other prominent sensory studies have combined different types of measures in one session; for instance, gathering dynamic emotion measurements and static hedonic liking (Cobo, Jager, de Graaf, Zandstra, 2022), or gathering static hedonic liking measures with taste quality and intensity measures.

This information could be utilised to better understand facial responses elicited during the consumption of commercially available dark chocolate in Experiment 2. Experiment 2 captured facial EMG data and offered insight into affective responses during the consumption of the same two dark chocolate samples (36% cocoa and 85% cocoa). In this experiment a 70% cocoa chocolate sample was added, as this sample is expected to be perceived as more bitter than the 36% cocoa sample and less bitter than the 85% sample and allows for a better understanding of responses linked to hedonic evaluation and sensory perception.

The overall objective of this study is to elucidate whether bitterness perception itself drives facial activity elicited during dark chocolate consumption, in a dose-dependent manner, or whether it is the hedonic evaluation of this attribute that is associated with the elicited facial activity. Thus, the predicted results would either: a) show that the *corrugator* muscle would distinguish the chocolate samples based on cocoa content during consumption; or b) that facial activity of the *corrugator* would be associated with self-reported liking scores of the chocolate samples, regardless of the cocoa content of the sample. It was also hypothesised that *zygomaticus* reactivity would increase as liking scores of the sampled chocolates increased during consumption, as this muscle is not typically involved in the facial expression of the bitterness, which instead generally involves the areas around the eyes and forehead.

2. Methods –Experiment 1 Temporal Dominance of Sensations

2.1. Participants

A total of 39 participants completed this lab-based study. The sample comprised 22 females, mean age 30, SD = 13. Participants were initially screened to check for exclusion criteria including any previous eating disorders, diagnosis of autism disorder, any neurological conditions, or allergies/sensitivities to any ingredients in chocolate. All participants reported good or corrected-to-good eyesight. The study was approved by the Ethics committee of the School of Applied Science, Abertay University. The study took approximately 1 hour to complete.

2.2. Materials

Participants also completed the Autism Quotient, The Glasgow Sensory Questionnaire, and the Leuven Embedded Figures Test. However, the results of the individual differences element of the study are not the subject of this paper.

2.3. Selection of the Temporal Dominance of Sensation attributes for dark chocolate

The TDS method is mainly used to differentiate products of the same category and requires a participant to choose the most dominant attribute at any given time during the tasting of a food product (Hutchings et al., 2014; Jager et al., 2014; Pineau et al., 2009; Pineau et al., 2012). As the dominant attribute changes the participant is required to select another from the available options until the tasting ends. From these aggregated data a TDS curve can be constructed showing the dominance rate (standardised as a proportion of the number of runs (number of participants x number of replicates) across time (standardised as a proportion of total time taken to complete sampling) (Pineau et al., 2009). Eight key sensory attributes related to dark chocolate were chosen from existing literature (Jager et al. 2014). The attribute list provided for the original study, from which the list was taken, included ten attributes but investigated flavoured dark chocolate. As the current study was testing only unflavoured dark chocolate, the two attributes "Fruity" and "Mint" were removed from Jager *et al.*'s original list. The final list included "bitter", "sour", "sweet", "cocoa", "crunchy", "dry", "melting", and "sticky". The order of attributes was randomised across participants and remained in the same position for all samples for each participant.

2.4. Procedure

The experiment took place in the consumer sensory booths of Abertay University. Following screening and informed consent participants completed information on their age and gender. Participants were tested in an individual booth equipped with a laptop computer. Standard white lighting was used. Participants completed the computer-based chocolate testing, the L-EFT, the Autism Quotient and Glasgow Sensory Questionnaire in a counterbalanced order. Prior to starting the chocolate tasting sessions, participants were introduced to the TDS method and the term "dominant" was explained in the same way to all participants as "the attribute that takes most attention, not necessarily the most intense". This involved differentiating the terms "dominant" and "intense" by giving examples. Each sensory attribute was explained, and a list with definitions was on hand for reference (taken exactly from the existing study by Jager et al. 2014). Participants were asked if they understood the explanation, and clarification was given where required. The chocolate tasting included two chocolate samples (5 g) presented in duplicate, varying in cocoa content (Lindt 85% and Bournville 36%, please see Table 1 for an ingredients list). Instructions were presented and responses logged in Compusense cloud (Compusense, Inc. Guelph, ON, Canada). Chocolate samples were presented in transparent, lidded containers with randomised three-digit codes. Testing of samples was carried out in random order with samples facing downward to conceal the brand name.

Table 1: Ingredients list of sampled chocolates

Chocolate	Manufacturer	Ingredients
Bournville		Sugar, cocoa butter, cocoa mass, vegetable fats (palm, shea), emulsifier (soya lecithin) (36% min cocoa)

Lindt 85% cocoa	**cocoa mass, fat-reduced cocoa, cocoa butter, demerara sugar, vanilla; cocoa solids: 85% min**

The chocolate tasting task required participants to rate the most dominant attribute throughout oral processing (when participant clicked the start button until clicking stop at the point of swallow). Participants were requested to place the product in their mouths and hold it for two seconds, then begin the tasting. Immediately after the TDS task, participants were asked to rate bitterness on a 10-point categorical scale with the anchors "*not bitter at all*" and "*extremely bitter*". They were then asked to rate their overall liking of the sample on a 10-point hedonic liking scale with the anchors "*extremely dislike*" and "*extremely like*". Following the testing of each sample, participants were instructed to cleanse the palate with fresh water during a 20-second break. Following completion of all tasks, participants were debriefed before leaving the lab.

2.5. Data Analyses

Paired t-tests or Wilcoxon signed-rank tests (where conditions of normality were violated) were run to investigate differences in participants' behaviour between chocolate samples on the variables liking, bitterness rating, number of attribute selections and the time taken to select the first attribute. For correlational analysis involving variables measured by Likert-type scales, such as liking ratings, Spearman's correlations were run.

TDS curves were averaged for all replicates and aggregated to give a sensory profile at the group level. Time was standardised (x-axis) and is shown as a proportion of the total time taken for participants to consume the sample. Dominance rates (y-axis) were calculated as the proportion of runs (number of subjects x number of replicates) where the attribute was chosen as dominant. A chance line (1/number of attributes) and a significance line (p<0.05) were also added to the curves (Pineau *et al*., 2009).

3. Results – Experiment 1

3.1. Differences between the sampling conditions

Participants rated the 36% chocolate sample higher in liking (Mean = 6.29, SD = 1.63) than the 85% sample (Mean = 4.4 SD = 1.79), t(38) = 4.61, p<.001. Bitterness ratings given by participants also significantly differed between their tasting of the 36% (Mdn = 2, IQR = 3) and 85% cocoa samples (Mdn = 7.45, IQR = 2.2), $Z = 5.36$, p<.001, with the 85% cocoa sample receiving higher bitterness scores as expected.

There was also a significant difference in the number of attribute selections participants made for the 85% cocoa sample (Mean: 4.81, SD = 1.5) and the 36% cocoa sample (Mean: 4.17, SD = 1.6), *t*(38) = 2.76, *p* = .009. However, there was no significant difference in the average number of unique attributes chosen while participants sampled the 85% (Mean: 5.05, SD = 1.23) and the 36% cocoa chocolate samples (Mean:4.62, SD = 1.33), *t*(38) = 1.74, *p* = .091. Thus, participants changed the dominant attribute more frequently for the 85% cocoa content sample than the 36% sample but did not choose more attributes overall. The average time taken for participants to select the first dominant attribute for the 36% sample (Mean:6.79 s, SD = 3.33) and the 85% sample (Mean:6.58 s, SD = 2.75) was not significantly different, *t*(38) = .44, *p* = .659. The time taken by participants to consume the samples was significantly different, with the 85% cocoa sample taking longer (Mean:40.4s, SD = 11) than the 36% sample (Mean:37.1s, SD = 11.74), *t*(38) = 3.02, *p* = .004.

3.2. TDS Curves for chocolate samples across participants

Crunchy, bitter, and dry were shown to be significant attributes for the 85% cocoa sample early on during tasting (<30% of total duration) and bitterness remained significant across the tasting period (Figure 1). Sourness was also significant at the latter stages.

During the early stages of oral processing, the dominant attributes of the 36% chocolate were *crunchy* and *sweet*. *Sweet* remained significant throughout. Approximately halfway through oral processing, *cocoa* became significant but dropped below significance at approximately 60% of standardised time. The textural properties *melting*, and *sticky* were shown to be significant at later stages in the process for the 36% cocoa sample.

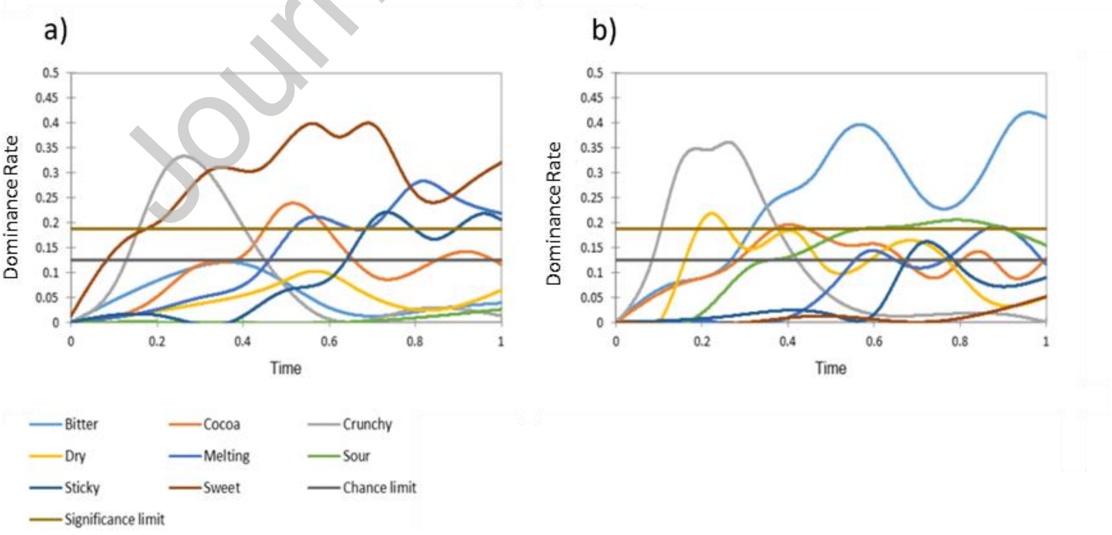

Figure 1: shows standardised TDS curves for a) the 36% cocoa sample, b) the 85% cocoa sample

3.3. *Dynamic evaluation*

Bitterness ratings for the 85% cocoa sample were positively correlated with bitterness ratings of the 36% cocoa sample (ρ = .403, *p* = .011), which implies that individuals perceiving higher bitterness ratings in the 85% sample also gave higher bitterness ratings for the 36% sample. Furthermore, bitterness ratings of the 85% sample negatively correlated with liking ratings (ρ= -.449, *p* = .004) (Figure 2). Thus, as perception of bitterness increased, liking decreased. This was not the case for bitterness ratings of the 36% sample and liking ratings (ρ = .092, *p* = .577).

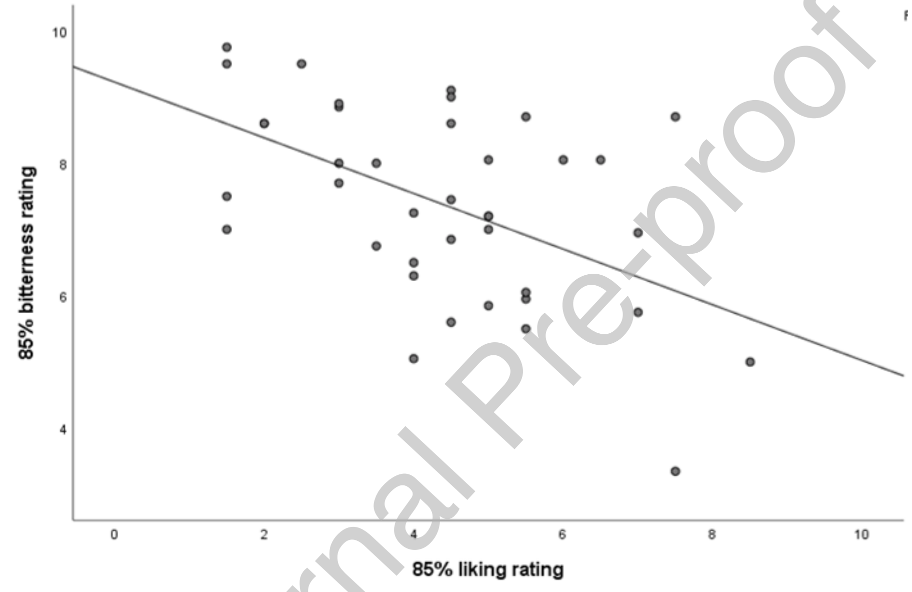

Figure 2: Relationship between liking and bitterness ratings for the 85% cocoa sample

4. Discussion – Experiment 1

The TDS curves may give some indication of the time points when facial activity may be expected in response to the dominant attributes. For instance, it appears that at around 40-60% of the way through the eating process bitterness and sourness are near their peak for the 85% cocoa sample, whereas for the 36% sample this is when sweetness is high. These results are similar to the temporal sensory profile constructed by an untrained group in a study by Jager et al. (2014) during the oral processing of the same chocolate - 85% cocoa from the Lindt Excellence series. Indeed, on referring to the sensory profile constructed by the consumer sample in their study, the dominance rate of bitterness is most apparent approximately 40 - 50% of the way through oral processing of the sample (Jager et al., 2014), and as such, supports the notion that this may be a good time for distinguishing the samples. However, it must be remembered that this is the standardised time point, as individuals will vary in the time taken to consume the products; as such, the time in seconds will differ between participants. Furthermore, the timing between recorded sensory perception of dominant attributes and facial response will differ given the motor processes required to respond. That is the conscious awareness of these sensory properties are likely to occur later than the automatic affective responses captured by facial EMG.

5. Materials and Methods – Experiment 2 Facial Electromyography

5.1. Participants

47 participants (28 female, mean age 32.2 years (SD = 12.2)) were tested. All participants were free of allergies or sensitivities to any of the ingredients in dark chocolate, none reported having a cold or suffering from any other ailment or condition that may affect tasting ability, nor did they report having any previous or current eating disorder, or a diagnosis of autism.

All participants reported good or corrected-to-good vision. Due to poor EMG recordings, the data of five participants were excluded from all analyses (42n), the data of one participant was excluded for *zygomaticus* only and another for *corrugator* only (41n) as data were not provided for all chocolate samples.

5.2. Facial EMG Data Acquisition

Facial muscle activity was recorded with the AD Instruments PowerLab data acquisition system and LabChart 7 software was used to analyse captured data. Bipolar 4 mm shielded Ag-AgCl electrodes were used on targeted muscles. An electrode attached to the forehead was used for grounding. Cleaning of the targeted areas (*zygomaticus* and *corrugator*) was carried out using abrasive pads and alcohol wipes. Electrode gel was applied to the face and used to fill the electrodes, which were placed on targeted areas as per instructions given by Fridlund and Cacioppo (1986). Electrodes were attached using adhesive collars. All EMG recordings were automatically annotated with comments time-locked to E-Prime stimuli presentation events and the video recording module was activated when the EMG recording started and finished when the EMG recording stopped. Videos of all subjects were viewed, and trials were removed where movement unrelated to the task was evident (coughing, talking, excessive body/mouth movements).

The EMG raw data were sampled at a rate of 2000 Hz/s with a 10 Hz high pass and 500 Hz low pass filter along with a 50 Hz mains filter. Signals were rectified and the baseline for all samples was calculated as the average EMG activity during a 500 ms restful period before the sampling experiment (note, that where there was an artefact during this time, the closest artefact-free 500 ms timebin prior to sampling was taken as the baseline). Thereafter, the dependent variable – the mean EMG change from baseline - was calculated by subtracting the mean baseline from the mean EMG values at different stages during the experiment. This included averaging data for the full consumption period (from the sample going in the mouth to swallow), during the thinking stage, after consumption of each sample when participants were asked to think about the experience, and for the full duration of the rating stage at the end of each instance of chocolate sampling. Change Scores (CS) were checked for each data point of interest and those +/- 3.29 SDs from the group mean were removed from analyses (Tabachnick, Fidell, Ullman, 2007).

5.3. BMI

Height measurements were taken by the researcher in the laboratory (in centimetres) using a stadiometer, with participants being asked to remove their shoes. Weight was also measured (in kgs) by the researcher in the laboratory using a set of Salter mechanical scales. Participants were asked to remove outerwear, such as jackets before being weighed. BMI was calculated using the standard formula BMI = kg/m^2.

5.4. Hunger ratings

Participants were asked to rate their current hunger levels on a scale of 1 (extremely full) to 10 (extremely hungry). This was carried out in paper format.

5.5. Chocolate sampling

Participants were required to taste a practice chocolate sample and three experimental samples, presented in small transparent containers with lids, with a random three-digit number used as an identifier. The practice chocolate sample (3 g) used was the same as the first chocolate sample for each participant, and the order of chocolate samples was counterbalanced. The dark chocolates sampled (5 g) included 36% (min) cocoa content Cadbury’s Bournville, 70% Lindt, and 85% Lindt. Samples were presented face down, as branding was apparent on the front of the chocolate and participants were asked to open the container and place the chocolate directly in their mouth.

5.6. Procedure

A cover story was used to ensure that participants’ knowledge of the purpose of the study did not bias their responses and change their facial activities. Participants were told that they would be involved in an experiment investigating changes in the body that take place during eating. Participants were told that signals from the body, including the frontal regions of the brain, would be captured. Following informed consent, screening, height, weight and reporting of hunger levels were completed as described in sections 5.3 and 5.4. Participants’ faces were cleaned, and target areas were abraded before electrodes were attached to the face. A five-minute period was given to allow the signal to stabilise. Following this period, a practice sample was given to the participants, which involved them tasting a very small sample of chocolate (approx. 3 grams) with the researcher explaining instructions as participants proceeded through the stages of consumption. These instructions were in no way concerned with the facial EMG element of the experiment and were only included to ensure participants knew at which points they were to press buttons to move on to the next stage of the sampling process. For instance, participants were told by the researcher to "press the button immediately following swallow of the full sample, that is, when no chocolate remains in the mouth" and to "ensure you fully cleansed your palate by drinking the available water as required during the 30-second break". All participants were requested to act as naturally as possible, and all participants were allowed to move their faces to allow them to experience that the electrodes were securely attached, to prevent participants from worrying unnecessarily and behaving unnaturally. To prevent any electrodes from being hit or becoming unattached participants were asked to make any big movements such as adjusting seating position during the breaks between samples. No data were kept from the practice sample, as this was only included to ensure participants understood all instructions. Participants were given time after the practice chocolate to ask questions and to ensure the palate was fully cleansed. Participants were then given instructions on-screen to press buttons during specific stages of consumption as described in Figure 3. The computer presenting E-Prime 3.0 Professional was connected to the PC running LabChart, which allowed for annotated comments to be entered onto the Lab Chart file as the experiment progressed.

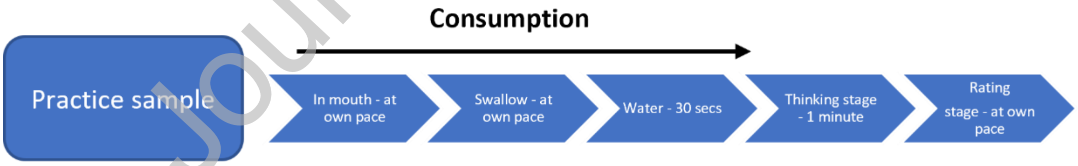

Figure 3: Chocolate sampling procedure. During consumption, participants were asked to press buttons to indicate when they had placed the sample in their mouth when all the sample had been swallowed. They were given a 30-second period where instruction was given to drink water and ensure full cleansing of the palate. They were thereafter presented with a one-minute thinking stage where they were instructed to think about the chocolate they had just tasted. At the end of each instance of chocolate sampling participants were asked to rate the chocolate using an on-screen Likert scale with 1 being extremely dislike and 10 being extremely like.

When the experimental session started the researcher sat out of view of the participant. Once the participant had sampled all chocolates as described in section they were requested to wait until the researcher returned to remove all electrodes. Participants were then thanked and debriefed.

5.7. Data Analysis

To investigate whether there were significant differences in muscle activity (for each muscle separately) elicited during the tasting of the chocolate samples varying primarily in cocoa content, repeated measures analyses were conducted, with chocolate sample (36%, 70%, 85%) as the within-subjects factor. For distinguishing the samples during the in-mouth stage, only the *corrugator* was considered as this muscle would be less affected by artefacts from movements related to oral processing of the chocolate and is involved in the typical frowning expression linked to bitterness perception.

To allow examination of the intra-individual association between muscle activity and pleasantness the rmcorr package (Bakdash, Marusich, Marusich, 2016) was used to estimate the common regression slope among participants (for each of the 3 chocolate samples of 41 participants). Correlations were also run to investigate whether hunger or BMI had any association with facial activity captured during oral processing. Where data were not normally distributed, non-parametric tests were adopted.

6. Results- Experiment 2

Hunger scores or BMI scores (detailed in Table 2) were not found to be related to ratings of any of the chocolate samples (all *ps* > .390).

Table 2: Details of the mean and standard deviations for BMI and hunger levels.

Individual difference measure	**Mean (SD+/-)**
BMI	25.3kg/m2 (4.38)
Hunger	4.37 (2.09)

The 70% sample received the highest liking rating by participants, followed by the 36% sample, and then the 85% sample (see Table 3). A Friedman test on liking ratings revealed there was a significant difference between participants' ratings given during each of the sampling conditions X^2_F (2) = 13.97, *p* = .001. Post-hoc Wilcoxon signed-rank tests (Bonferroni adjustment α = .017) showed that the difference was between the most bitter 85% sample and the other two samples. Participants rated the 85% cocoa content sample lower than the 36% sample, *Z* = -2.5, *p* =

.013, and lower in liking than the 70% sample, *Z* = -4.01, $p < .001$. There was no significant difference in liking ratings between the 36% sample and the 70% sample, $p = .705$.

Table 3: Medians and IQRS of self-reported liking ratings for each chocolate sample varying in cocoa content.

Sample cocoa content	**Median**	**IQR**
70%	7	4
36%	6.5	4
85%	5	3

6.1. During consumption – distinguishing the samples by facial activity

The 85% sample (*Mdn* = 4.5 µV, IQR: 6.12) evoked the largest *corrugator* activity; however, the 70% (*Mdn* = 2.67 µV, IQR: 4.68) and 36% samples (*Mdn* = 2.67 µV, IQR: 5.73) evoked similar changes in facial activities. A Friedman test on *corrugator* activity during consumption revealed there was no significant difference during each of the sampling conditions for participants, $X^2_F(2) = 5.902$, $p = .052$. Post-hoc Wilcoxon signed ranks tests revealed a significant difference between the 85% sample and 36% sample *Z* = 2.56, $p = .010$, but not the 85% sample and the 70% sample ($p = .316$), nor the 70% and 36% samples ($p = .626$).

6.2. Intra-individual correlations – repeated measurements of pleasantness and *corrugator* activity

It was found that *corrugator* activity was negatively associated with self-reported pleasantness ratings of chocolate samples (*rmcorr* = -.40, [-0.57, -0.21], $p < .001$), and *zygomaticus* activity was negatively associated with self-reported pleasantness ratings of the chocolate samples. Nonetheless, the *zygomaticus* results were neither notable in terms of effect size nor were they significant, (*rmcorr* = -.02, [-0.36, 0.06], $p = .15$).

6.3. Analyses of facial activity during oral processing when TDS curves displayed differences in bitterness/sweetness perception between the 85% and 36% samples.

A Wilcoxon-signed ranks test carried out on *corrugator* activity two-thirds of the way through oral processing showed a significant difference between *corrugator* activity captured during the processing of the 85% sample and the 36% sample, *Z* = -2.13, $p = .033$. As may be expected the 85% more bitter sample evoked greater *corrugator* activity (*Mdn* = 3.89µV, IQR: 5.5) than the 36% sample (*Mdn* = 3.17µV, IQR: 5.69).

6.4. Group differences based on chocolate preference during the in-mouth stage

Each participant with *corrugator* data for all samples (n = 41) was checked for their preferred chocolate and two independent groups were constructed based on whether the sample with 36% cocoa content was preferred over the 85% cocoa content sample. This resulted in 28 preferring the 36% cocoa content sample and 11 preferring the 85% cocoa content sample, and 2 participants rating the samples the same. Age, BMI, and hunger levels did not differ between the groups (see Table 4).

Table 4: Means and standard deviations of key individual differences for each group based on chocolate preference

	Group preference	**Mean (SD)**	
	36%	**85%**	***p***
Hunger	4.19 (2.01)	4.73 (2.24)	.477
BMI	25.0 (4.35)	26.34 (5.03)	.413
Age	31.5 (13.45)	33.09 (9.49)	.723

A mixed ANOVA was run on *corrugator* activity at the time when bitterness and sweetness most differed on the TDS graphs of the 36% cocoa and 85% cocoa samples, with chocolate sample (36%, 70%, 85%) as the within-subjects variable and preferred chocolate sample as the between-subjects variable. This revealed there was no difference in *corrugator* activity based on the groups $p = .530$. Thus, the group preferring the 36% chocolate elicited similar activity to the group preferring 85% chocolate overall. There was no main effect of sample $p = .712$. However, there was an interaction between the chocolate sample being consumed and the preferred chocolate group, F (2, 74) = 5.19, $p = .008$. Therefore, the *corrugator* activity elicited for the three samples differed according to the participant's preferred chocolate group. It was found that this was driven by the variation between the *corrugator* activity elicited while sampling the 36% cocoa content sample with the group preferring the 36% sample eliciting lower *corrugator* activity than the group preferring the 85% cocoa content sample $t(37) = 2.061$, $p = .046$. The groups did not differ significantly while oral processing the 70% or 85% samples (all *p*s > .846). However, when non-parametric follow-up tests were conducted, the difference between *corrugator* activity elicited by the groups while sampling the 36% cocoa content sample was no longer significant ($p = .054$), nor was the parametric test significant following Bonferroni corrections.

When the same analysis was carried out for the mean *corrugator* activity elicited during the full consumption time there was no difference in activity based on the groups $p = .334$. Nor was there a significant effect of chocolate being sampled ($p = .279$). However, there was an interaction between chocolate being sampled and the preferred chocolate group, F (2, 74) = 5.868, $p = .004$. Again, it was found that this was driven by the *corrugator* activity elicited by the groups when sampling the 36% cocoa content sample with the group preferring the 36% sample eliciting lower activity than the group preferring the 85% sample (see Figure 4), $t(37) = 2.667$, $p = .011$. The groups did not differ significantly while oral processing the 70% or 85% samples (all ps > .818). A Mann-Whitney U test also showed a significant difference between *corrugator* activity elicited between the two groups while sampling the 36% cocoa content sample ($U = 79.00$, $p = .018$). Thus, although all time points suggest facial activity is linked to hedonic liking and not solely to influential taste attributes, including bitterness. The fact that the groups did not differ on corrugator activity of the 85% cocoa sample, which elicits high dominance ratings of bitterness during consumption, may suggest that at high intensities sensory attributes, including bitterness themselves do influence corrugator activity. Thus, to distinguish samples, based on facial activities linked to hedonic preference, it may be best to avoid targeting times when key dominant taste attributes, such as bitterness and sweetness deviate the most between samples as these sensory properties are also likely to influence facial activities.

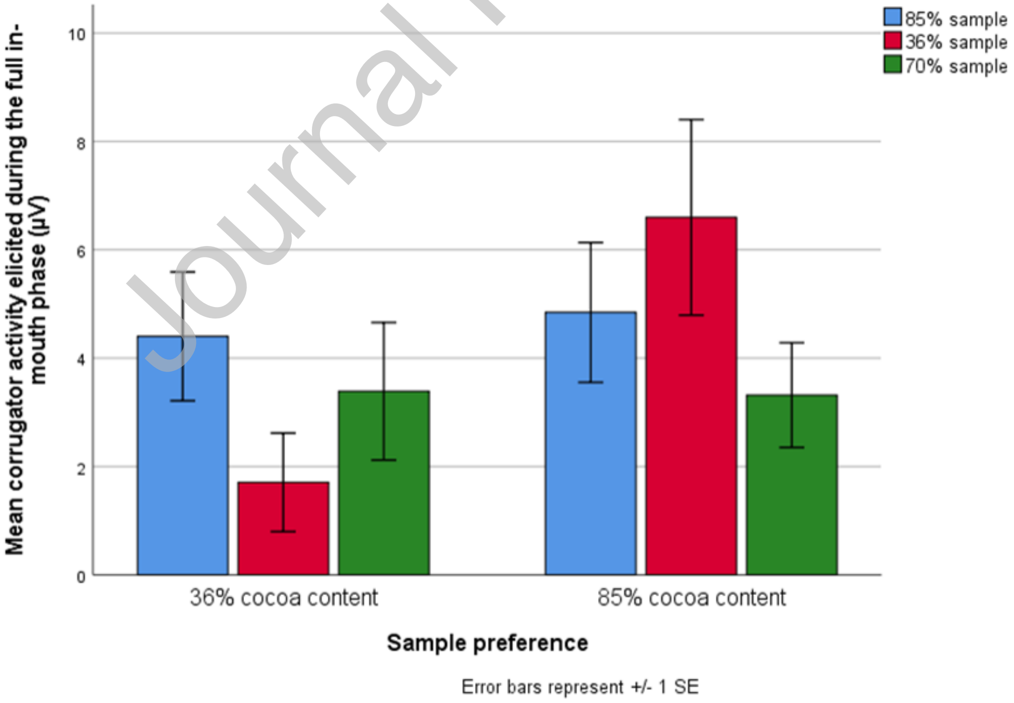

Figure 4: Mean corrugator activity elicited during the in-mouth stage of oral processing the chocolate samples

6.5. Exploratory Analyses

6.5.1. Thinking stage

The thinking stage was not analysed as it was found that many people did not pay attention during this stage and used this time to cleanse their palate or make mouth movements. Thus, no analyses were carried out.

6.5.2. Rating stage – distinguishing the samples

The most bitter 85% sample (*Mdn* = 1.58 µV) evoked the largest *corrugator* activity, followed by the 36% sample (*Mdn* = 1.13 µV) and then the 70% sample (*Mdn* = .73 µV). A Friedman test on *corrugator* activity during the rating stage showed significant differences between the sampling conditions $X^2_F(2) = 6.05$, $p = .048$. Wilcoxon signed ranks tests revealed this was driven by the difference in activity during sampling of the 85% and 70% samples $Z = -2.7$, $p = .007$. There was no significant difference in activity when sampling the 36% and 85% samples ($p = .056$) or the 36% and 70% samples ($p = .882$). A Friedman test revealed there was no significant difference found in *zygomaticus* reactivity during the rating of the samples ($p = .751$).

6.5.3. Hunger and BMI

Hunger or BMI were not found to be associated with facial activity during the rating or in-mouth stages of chocolate consumption or with self-reported liking of the samples (all *p*s > .074).

7. Discussion – Experiment 2

This study allowed for an investigation into the variations in facial activity that take place during consumption of chocolate samples varying in cocoa content. Specifically, this experiment set out to investigate whether facial activity of the *corrugator*, linked to negative affect, would be associated with bitterness of the samples in a dose-dependent manner or whether activity would be associated with hedonic responses during the consumption of three commercially available samples of dark chocolate varying primarily in cocoa content. Furthermore, it was expected that *zygomaticus* activity would be positively associated with the self-reported hedonic liking of the chocolate samples. The hypothesis was partially supported in that *corrugator* activity was found to be significantly associated with self-reported liking of the samples. This was not the case for the *zygomaticus*. Our results of Experiment 1 found key differences in the dominant taste attributes bitterness and sweetness, a significant variation in liking ratings was also found with the sample having bitterness as more dominant in its profile being liked less (85% cocoa). The results of this experiment show significant differences in the corrugator activities elicited during consumption of both samples in the direction expected, with the liked sweeter sample evoking less corrugator activity. However, as the sample perceived to be most bitter is also the sample least liked it is not known whether it is the bitterness itself driving results or the liking of the samples, including the sensory attributes such as bitterness. By including the 70% cocoa sample, which has previously been shown to have a sensory profile characteristic of a chocolate lower in bitterness than the 85% sample (Jager et al., 2014), and is found to be higher in bitterness when compared with the TDS graph produced in this study for the 36% cocoa, it is possible to start investigate whether facial variations are down to hedonic liking or based on the perception of influential sensory attributes, such as bitterness. Participants rated the 85% cocoa sample significantly lower than the 36% cocoa sample and lower than the 70% cocoa sample. No significant difference in liking ratings was found between the 36% sample and the 70% sample. Thus, it should be expected that the facial activity would be higher for the 70% sample than the 36% sample if bitterness perception was driving the results. However, this was not the case, and the similar results suggest that hedonic liking drives *corrugator* activity elicited during consumption of dark chocolate varying in cocoa content, rather than perception of influential attributes such as bitterness. The *corrugator* activity elicited during the consumption of the 36% cocoa sample also significantly differed from the 85% sample in the direction expected based on liking. However, it would also be expected that the 70% cocoa sample would elicit *corrugator* activity that differed significantly from that elicited during the consumption of the least liked 85% cocoa sample if such activity captured variations in affective response to dark chocolate samples. This was not the case, with no significant differences in *corrugator* activity found during consumption of these samples. Thus, it would not be possible to distinguish the samples based using *corrugator* activity, however, self-reported liking could be used to distinguish the samples. Zygomaticus activity, an indicator of positive emotion was not found to distinguish the samples based on liking. Previous research has shown facial displays to be an inconsistent indicator of hedonic evaluation when using complex food products; for instance, finding them to be a good indicator of negative experience but unable to distinguish variations in pleasant foods varying in liking and sensory attributes (e.g., De Wijk, Kooijman, Verhoeven, Holthuysen, De Graaf, 2012; Gunaratne, Fuentes, Gunaratne, Torrico, Gonzalez Viejo, Dunshea, 2019).

It may be that as these two samples are both high in cocoa content, the sensory drivers limit the ability of sensory responses to distinguish the samples. When dividing participants into groups the data show a variation in *corrugator* response to the 36% chocolate based on liking, with individuals who liked the 85% cocoa better eliciting more activity, indicative of dislike. There was no difference in activity elicited for the 85% cocoa sample based on liking, which may be due to high levels of bitterness eliciting ceiling effects. That is, dark chocolate perceived as bitter may elicit corrugator activity of a certain level even when liked. Thus, for commercially available dark chocolates with different sensory profiles, including variations in bitterness perception, understanding implicit affective responses can be challenging. However, when looked at in terms of individual responses, self-reported hedonic liking was associated with *corrugator* activity in the expected direction and suggests facial EMG may be another tool to aid understanding of the consumer experience.

8. General Discussion (Experiment 1 and 2)

The primary objective of this study was to investigate whether bitterness perception drives activity of the *corrugator* during dark chocolate consumption, in a dose-dependent manner, or whether it is the hedonic evaluation of such sensory attributes that is associated with elicited facial activity. The experiments in this combined study were conducted to gain an insight into how sensory perception and facial affective response during eating may be linked in untrained consumer samples. Research has captured changes in facial activities, linked to affect, to aid the prediction of consumer behaviour in line with the increasing focus on combined implicit and explicit methods to better understand the total consumer experience (Lagast, Gellynck, Schouteten, De Herdt, De Steur, 2017). However, such methods require further testing to give offer insight into whether they offer information over and above traditional self-reporting methods or whether they provide a different insight into the consumer experience. This study aimed to shed light on the association between temporally dynamic self-reported sensory profiles of commercially available dark chocolate primarily varying in cocoa content and the facial activities elicited during their consumption.

Studies adopting taste paradigms and capturing facial EMG have been carried out (Cannon et al., 2017; Horio, 2003; Hu, Luo, & Hui, 2000). Two of these cited studies reported the *corrugator* to be associated with self-reported hedonic ratings, albeit with varying statistical analyses adopted across the studies. However, frowning has also been shown to be linked with bitterness intensity and often liking and bitterness intensity are highly (negatively) correlated during tasting, thus, it is difficult to discern whether it is dose-dependence or hedonic aspects of the tastant driving results (Wendin, Allesen-Holm, Bredie, 2011). Stimuli with more complexity have been investigated in studies using gel-type food, also showing an association between facial activity of the corrugator and hedonic liking (Sato, 2021). However, in commercially available dark chocolate, as was sampled in the current study, there is more sensory complexity which may drive results. Thus, this study tested whether the association between facial activity and hedonic liking still holds when used during the consumption of a food that can be high in cocoa content, known to have a relationship with bitterness perception, a taste that is known to elicit a characteristic negative facial reaction. Our results suggest that for dark chocolate samples corrugator activity can be linked with hedonic liking. However, when the samples have very different sensory profiles, such as in this study, it may be difficult to understand facial responses and their drivers.

If facial electromyography is to be used for better understanding responses to solid commercially available foods, knowing the optimal time bin to target for data is important, as there is a great deal of facial activity that can take place as part of oral processing in general, as such, knowing the time bins most appropriate for affective response to sensory properties would aid interpretation of the data. It is also the case that individuals will have different chewing styles (Foster et al., 2011) and the temporal aspects of the sensory properties of food may change based on these differences. Thus, selecting a broader but targeted time bin, which has been evidenced as important for sensory aspects of the samples across a group of individuals, may allow for a more refined investigation of the affective responses the product elicits than targeting standard time bins (i.e., every 500ms).

Finally do these results provide sufficient evidence to consider using both facial activity capturing tools and combining this with sensory information? To get a more complete picture of the consumer experience. It appears that combining complementary methods that include both implicit and explicit responses is one way forward for a better understanding of consumer behaviour (de Wijk & Noldus, 2021). Here, we choose to investigate temporally dynamic sensory information, facial affective responses, and static hedonic liking responses all from untrained consumers. Our results suggest that facial responses are associated with hedonic liking ratings but are likely to reflect other processes going on during consumption. However, if these facial responses were very highly associated with hedonic response, then arguably, there would be little point in collecting them as, in most circumstances, the self-reported method is likely to be cheaper and easier to obtain. As it stands, there appears to be more work required to better understand the facial responses elicited for dark chocolate. Future work may wish to test this with a greater number of chocolate samples varying in cocoa content. It may also be prudent to gather data on familiarity of eating the samples, with participants' buying behaviour gathered for a better understanding of their expectations and preferences when it comes to dark chocolate.

In terms of the negative association between self-reported hedonic liking and *corrugator* activity, the findings are in line with those put forward by Sato *et al.* (2021) in their investigations into facial and physiological responses during the consumption of solid food. However, as the current experiment involved the investigation of a complex food, controls between samples are less stringent. For instance, the 36% and 70% cocoa samples in our study had a similar mean liking rating although their dynamic sensory properties differ in many ways. This is a challenge when trying to take scientific methods to real-world contexts but allows for an understanding of the potential value a method could offer in an applied environment.

8.1. Limitations

Using different panels – may have had a different sensory experience (however TDS data from 85% cocoa content sample in line with Jager et al, 2014)

Sensory aspects being chosen from a list – participant may choose best fit rather than accurate reflection of their experience.

70% sample not included in sensory profile, but this profile produced from an untrained consumer sample has been established in previous research and the interest was in the sensory differences between the samples with the most and least cocoa content.

The 70% cocoa content sample was not included in Experiment 1, as such it may be questioned as to whether this is perceived as more bitter than the 36% cocoa content sample and less bitter than the 85% sample in an untrained consumer sample, as cocoa content does not always have a linear relationship with bitterness perception ratings. However, a previous study by Jager et al (2014) constructed TDS curves for this (70% Lindt) sample with an untrained consumer group. The temporal sensory findings suggest that for the 70% taste attribute sweetness did not exceed the significance level, unlike the 36% cocoa content sample tested in the current experiment. However, in the Jager study, the 70% cocoa content sample was found to be sweeter and less bitter than the 85% cocoa content sample (same sample by the same manufacturer also investigated in the Jager study) during consumption. Thus, together these findings suggest that the 85% cocoa content sample is perceived as most bitter, followed by the 70%, then the 36% cocoa sample, and further suggests that it is the hedonic nature of food samples that influence facial affective response rather than the intensity of taste levels associated with specific facial displays, in this case bitterness.

Facial EMG is intrusive, which may affect participant response – but allows for subtle differences, targeted in areas related to a key muscle variation during a facial reaction (frowning) that has been linked with affective response to bitter substances (e.g., Wendin, Allesen-Holm, Bredie, 2011). Furthermore, this study was carried out in consumer sensory booths and it may be the real value of capturing facial activity comes from eating during social interactions as facial expressions are primarily used in communication.

9. Conclusion

Facial EMG has the potential in future studies to help understand consumer response to food. However, although it is linked to hedonic liking of commercially available chocolate samples, the sensory variations in such samples mean that it is challenging to use the tool to distinguish samples based on mean liking, which is better carried out using self-reporting methods.

Competing Interests

No commercial or financial relationships exist that could be regarded as a conflict of interest.

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